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(54) **Process and apparatus for measuring the biocurrent distribution.**

(57) A process and an apparatus for measuring the biocurrent distribution are disclosed. Multiple current more than the number of isolated currents possibly existing in a living body are assumed and the virtual magnetic field created by the assumed currents at actual measuring points (12-1, ..., 12-M) is calculated. The estimated location and current vectors of said assumed currents are consecutively changed to decrease the difference between said virtual and actual magnetic fields so that the estimated location and current vectors of the assumed currents having the number corresponding to the true isolated currents substantially approximate to the true values and the estimates of the other assumed currents approximate to zero. This enables the biocurrent distribution to be exactly determined even when the number of isolated currents (q_n) is not preliminarily known.

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BACKGROUND OF THE INVENTION

The present invention relates to a process and an apparatus for measuring the biocurrent distribution and in particular to a process and an apparatus for indirectly measuring the biocurrent distribution by measuring the biomagnetic field and estimating the distribution of the biocurrents which are sources of the magnetic field based upon the measured data.

Estimation of the biocurrent distribution from the measured values of the biomagnetic field is usually performed as follows:

Description will be made by way of a neuromagnetic measurement which is a typical biomagnetic field measurement.

The coordinate system is defined as shown in Fig. 1. It is assumed that a current represented as a vector q_n exist in position r_n in the drawing. Such an isolated current vector can be assumed as far as the interface of the brain can be considered as spherical surface in the field of neuromagnetic field measurement and this current vector will be referred to as current dipole. A reference r_m in Fig. 1 denotes the coordinate of measuring point.

If it is assumed that N current dipoles exist in the brain, the magnetic flux density vector B_m at point r_m can be expressed from Biot-Savart's law as follows:

$$B_m = \sum_{n=1}^{N} \frac{\mu_0}{4\pi} \frac{q_n \times (r_m - r_n)}{|r_m - r_n|^3} \quad \ldots\ldots (1)$$

The magnetic field component which can be measured by a magnetometer is the component of B_m normalto the surface of the brain. The actual value measured at r_m is denoted as D_m.

If estimated location and current vectors of each dipole is expressed by superscripting a reference mark ^, the virtual measured value $\hat{D}_m$ which is calculated from the estimates is expressed as follows:

$$\hat{D}_m = \sum_{n=1}^{N} \frac{\mu_0}{4\pi} \frac{\hat{q}_n \times (r_m - \hat{r}_n) \cdot r_m}{|r_m - \hat{r}_n|^3 \; |r_m|} \quad \ldots\ldots (2)$$

A cost function is herein defined as follows:

$$E(\hat{r}_1, \hat{r}_2, \ldots \hat{r}_N; \hat{q}_1, \hat{q}_2, \ldots \hat{q}_N) = \sum_{m=1}^{M} (D_m - \hat{D}_m)^2 \quad \ldots\ldots (3)$$

Equation (3) shows the degree of matching between an estimated data and an actually measured data.

Optimum estimated values have heretofore been determined as $\hat{r}_1, \ldots, \hat{r}_N, \hat{q}_1, \ldots, \hat{q}_N$ which minimize the cost function defined by the equation (3).

It is found from the foregoing that the number N of the biomagnetic field sources, that is, the current dipoles should be known in order to carry out conventional measuring method. In other words, the conventional method can be carried out only if the number of the current dipoles is known.

If N which is different from the number of actual current dipoles is preset and a solution of $\hat{r}_1, \ldots, \hat{r}_N, \hat{q}_1, \ldots, \hat{q}_N$ which minimizes the cost function is determined, the solution would then show a distribution different from the actual biocurrent distribution.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a process and an apparatus for measuring the biocurrent distribution which is capable of obtaining a solution exactly showing the biocurrent distribution even if the number of the magnetic field sources, that is, the exact number of the current dipoles in a living body to be measured is not known.

In order to accomplish the above-mentioned object, in accordance with the present invention, multiple currents larger than the numbers of the isolated currents which are expected to exist in a living body are assumed, a virtual magnetic field created by the assumed current at the actually measured point is calculated. Estimated location and current vectors of the assumed current are changed to reduce the difference between the virtual magnetic field and the actual magnetic field for determining the optimum estimates. In this case, the absolute values of the excess assumed current vectors are approximated to zero.

If the multiple isolated currents, for example, the current dipoles larger than the number of currents actually existing are assumed and the estimates are changed so that the matching between the distribution of the magnetic field calculated from the assumed current dipoles and the distribution of the actually measured magnetic field is enhanced, an excessive freedom degree would be introduced. Accordingly, there is the high possibility that a solution different from the actual current distribution is obtained. In other words, it is to suppose that the magnetic field formed at the measuring point may be substantially equal to the magnetic field formed by the current dipole assumed as true current dipole (refer to equation (1)), if the current vector of the current dipole which is assumed to locate in a position closer to the measuring point than the position of the true current dipole is smaller than the true current dipole.

Hence, in accordance with the present invention, a fact is considered that the assumed current dipoles are more than the true current dipoles in magnitude by the number of the assumed current dipoles over the number of true current vector of the assumed current dipoles if the assumed current dipoles are compared with the true current dipoles in only magnitude or the energy (for example, magnetic field) which they give.

That is, when optimum values of the estimated locations and current vectors of the currents are determined so that the difference between the magnetic field calculated from the assumed currents and the actual magnetic field becomes smaller, the excessive freedom degree of the optimum values is restricted by decreasing the magnitude of current dipoles or the energy that they give so that the optimum values of the current vectors of the assumed currents which is an excess over the number of the true currents approximate to zero.

In the present invention, an excessive freedom degree is restricted by using the total sum or the total sum of α-th power of the absolute values of the current vectors of the assumed current dipoles, or the total sum of the magnitudes of the magnetic fields, each formed solely by each assumed current dipole or the total sum of α-th power of the magnitudes thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view illustrating an embodiment of neuromagnetic field measuring of the present invention and the coordinate system used for estimation of magnetic field sources; and

Figs. 2A and 2B are flow charts showing a process of simulated annealing of the present embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be described with reference to a neuromagnetic field measurement.

The neuromagnetic field measurement is conducted by measuring the component of the magnetic field in a direction normal to the brain surface at measuring points around a head while moving a magnetic flux meter 10 from points 12-l to 12-M as shown in Fig. 1. Presumption of space coordinates and current vectors of current dipoles in the brain which are sources of generating magnetic fields can be conducted based upon the measured values at measuring points around the head is accordance with present invention as follows:

The number of the measuring points on the surface of the head is assumed as M and the measuring points are numbered from l to M. The position of the m-th measuring point is represented by a vector r_m. The measured value of the magnetic field at that point is represented as D_m.

It is assumed that N current dipoles are contained in the brain. The present invention is applicable to a case in which an exact number of the dipoles are not know. The N is for a time preset larger than the number of the dipoles which are expected to exist in the brain.

The estimated location and current vectors of the thus assumed current dipole are represented $\hat{r}_n$ and

$\hat{q}_n$, respectively wherein n = 1, 2, ..., N. The magnetic field $\hat{D}_m$ (m = 1, 2, ..., M) which is created at the measuring points by the thus assumed current dipoles is determined by an calculation. That is, $\hat{D}_m$ can be referred to as the measured value of a virtual magnetic field determined from the assumed current dipoles. If the surface of the head is approximated by a spherical face and the center of the sphere is assumed as an origin of the coordinates, $\hat{D}_m$ is calculated by an equation as follows:

$$\hat{D}_m = \sum_{n=1}^{N} \frac{\mu_0}{4\pi} \frac{\hat{q}_n \times (r_m - \hat{r}_n) \cdot r_m}{|r_m - r_n|^3 \; |r_m|} \quad \ldots\ldots (2)$$

By an optimization operation which will be described in detail, the estimated location and current vectors of the assumed current dipoles are changed so that a minimum value which the cost function assumes is determined.

Following equation is used as the cost function in the present embodiment.

$$E(\hat{r}_1, \hat{r}_2, \ldots, \hat{r}_N; \hat{q}_1, \hat{q}_2, \ldots, \hat{q}_N)$$

$$= \sum_{m=1}^{M} (D_m - \hat{D}_m)^2 + Es(\hat{q}_1, \hat{q}_2, \ldots, \hat{q}_N) \quad \ldots\ldots (4)$$

The first term of the right formula of equation (4) denotes matching between the distribution of the actually measured magnetic field and the distribution of the magnetic field created by the assumed current dipoles. If the respective distributions are represented by row vectors G and $\hat{G}$, the first term can be represented as $|G - \hat{G}|^2$ wherein

$$G = \begin{pmatrix} D_1 \\ D_2 \\ \cdot \\ \cdot \\ D_M \end{pmatrix} \qquad \hat{G} = \begin{pmatrix} \hat{D}_1 \\ \hat{D}_2 \\ \cdot \\ \cdot \\ \hat{D}_M \end{pmatrix}$$

On the other hand, the second term in equation (4) is assumed as the sum total of the magnetic fields, each created by individual assumed current dipole. The detailed form of Es (q_1, q_2 ..., q_N) is as follows:

$$Es(\hat{q}_1, \hat{q}_2, \ldots, \hat{q}_N) = w \sum_{n=1}^{N} |g_n| \quad \ldots\ldots (5)$$

wherein

$$g_n = \begin{pmatrix} g^1{}_n \\ g^2{}_n \\ \cdot \\ \cdot \\ g^M{}_n \end{pmatrix} \qquad \cdots\cdots (6)$$

and $g^m{}_n$ is calcutated as follows:

$$g^m{}_n = \frac{\mu_0}{4\pi} \frac{\hat{q} \times (r_m - \hat{r}_n) \cdot r_m}{|r_m - \hat{r}_n|^3 \cdot |r_m|} \qquad \cdots\cdots (7)$$

The component $g^m{}_n$ in a direction normal to the surface of the brain (the component vertical to the face of a detecting coil) of the magnetic field created at the m-th measuring point by n-th current dipole is calculated by equation (7) for each $m = 1, 2, \ldots, M$. The magnitude of the row vector g_n having respective components, that is, the norm $|g_n|$ of the magnetic field created by the n-th current dipole is calculated. Specifically, the root of the sum of the square of the normal component of the magnetic field created by n-th current dipole at each measuring point is calculated. The magnetic field $|q_n|$ individually created by each assumed current dipole is determined in such a manner and the sum total with respect to n assumed current dipoles is determined to provide Es in equation (5).

Es $(\hat{q}_1, \ldots, \hat{q}_N)$ represented by equation (5) serves to suppresses the excessive freedom degree introduced by assuming the dipoles move than the number of actually contained dipoles. Although it is hard to logically and exactly verify this in case of non-linear inverse problem like the estimation of the magnetic field source in the brain which in an object of the present invention, linear inverse problem can be mathematically verified. This verification is discussed in H. Haneishi et al. "An analysis of cost function used in simulated annealing for CT image reconstruction", Applied Optics in Press.

"w" in equation (5) is a constant for weighting the first and second terms in the right expression of the equation (4). "w" is preset by preliminarily calculating ΔE as a trial so that the contribution is not biased to only one of the first and second terms in equation (4) when a change in the cost function ΔE is calculated for optimization operation which will be described hereafter.

Although equation (5) may be directly used as term of Es in equation (4), it is more preferable to use as reformed equation as follows:

$$Es(\hat{q}_1, \hat{q}_2, \ldots, \hat{q}_N) = w \sum_{n=1}^{N} |q_n|^{\alpha} \qquad (5)'$$

wherein an index of power α is a positive real number.

The role of α in equation (5') is as follows:

True current distribution is estimated by assuming the current dipoles more than the number of the current dipoles which are expected to exist in the brain in the present invention. Accordingly, there is the possibility that a plurality of current dipoles are estimated in substantially same position. α in the equation (5') determines the nature of the solution obtained in such a case. A case in which two current dipoles u-th and v-th are estimated in substantially same position, that is, a case in which $\hat{r}_u \doteqdot \hat{r}_v$ will now be exemplarily described.

(1) In case of $0 < \alpha < 1$, either one of the current vectors q_u and q_v of the u-th and v-th current dipoles becomes very small. That is, $|\hat{q}_u| \doteqdot 0$ or $|\hat{q}_v| \doteqdot 0$. In other words, one current vector of a plurality of current vectors having interposed space coordinates approximates to the current vector of a current

dipole which inherently exists in that position and the magnitudes of the current vectors of the other current dipoles become substantially zero.

(2) In case of $\alpha > 1$, $\hat{q}_u \doteqdot \hat{q}_v$. These values are about a half of the value of the current vector of the current dipole which inherently exists in position $r_u \doteqdot r_v$.

(3) In case of $\alpha = 1$, a value $\hat{q}_u + \hat{q}_v$ approximates to a current vector value of the current dipole which exists in position $r_u \doteqdot r_v$. Which value a ratio $|\hat{q}_u|$ to $|\hat{q}_v|$ assumes cannot be predicted.

Briefly, it is preferable that α be other than 1, and $0 < \alpha < 1$ is most preferable (for example, $\alpha = 1/2$).

An optimization operation which determines estimates $\hat{r}_n$, $\hat{q}_n$ $(n = 1, ..., N)$ for making minimum the cost function E $(\hat{r}_1, ..., \hat{r}_N; \hat{q}_1, ..., \hat{q}_N)$ defined by equation (4), more specifically equation (5) or (5') will be described in detail. The cost function E is non-linear with respect to the variable and has a localized minimum value. Accordingly, it is impossible to determine a true minimum value (a global minimum value) by known non-linear optimization approaches. The present embodiment adopts a recently proposed simulated annealing method which can determine a global minimum value even in such a case.

This method will now be described with reference to Figs. 2 A and B.

The above-mentioned N current dipoles are assumed and a proper value is preset as an initial value for respective coordinate r_n $(n = 1, ..., N)$ and current vector q_n $(n = 1, ..., N)$ is preset as a variable X_n $(n = 1, 2 ..., N)$ and the current vector q_n $(n = 1, 2, ..., N)$ of each current dipole is preset as a variable X_n - $(n = N+1, N+2, ..., 2N)$. The values of the cost function E which has been described in detail are calculated by using the actually measured and recorded values D_m $(m = 1, ..., M)$ of the magnetic field (step 101).

Thereafter, the value of X_n is changed by a very small amount (this is referred to as trial). Whether or not the trial is accepted is determined with reference to a change ΔE in the cost function E occurred by the trial. The value of each X_n is gradually approximated to the true value.

Firstly, a sufficiently high parameter T is preset. The parameter T determines the probability that the change is accepted even if $\Delta E > 0$, and is referred to as temperature.

ΔE is calculated by a trial calculation and T is preset so that $\exp(-\Delta E/T) = 0.8$ to 0.9. The changes $|\Delta\hat{r}|$ and $|\Delta\hat{q}|$ in one trial are preset for variables $\hat{r}_1, ..., \hat{r}_N$ and $\hat{q}_1, \hat{q}_2, ..., \hat{q}_N$, respectively. (step 102)

It is adequate that the value of $|\Delta\hat{r}|$ be about 1 mm to 10 mm and the value of $|\Delta\hat{q}|$ be about 1/10 to 1/1000 of a predicted maximum value of $|\hat{q}|$.

Then, respective initial values zero are preset for parameters N_T, N_1, N_2 for repeated control of the trial (step 103).

One variable X_n which will be an object of the trial is then chosen (step 106) to determine a change in vector ΔX_n (step 107). If the variable X_n is a coordinate, following equations are used.

$$\left.\begin{aligned}(\Delta x_n)_X &= |\Delta\hat{r}|\sin\theta\cos\psi\\(\Delta x_n)_Y &= |\Delta\hat{r}|\sin\theta\cos\psi\\(\Delta x_n)_Z &= |\Delta\hat{r}|\cos\theta\end{aligned}\right\}\quad(8)$$

If the variable X_n is a current vector, the following equations are used.

$$\left.\begin{aligned}(\Delta x_n)_X &= |\Delta\hat{q}|\sin\theta\cos\psi\\(\Delta x_n)_Y &= |\Delta\hat{q}|\sin\theta\cos\psi\\(\Delta x_n)_Z &= |\Delta\hat{q}|\cos\theta\end{aligned}\right\}\quad(9)$$

The change in vector is determined by generating uniform random numbers θ and ψ in the ranges of 0

$\leqq \theta < 2\pi$ and $0 \leqq \psi \leqq \pi$, respectively.

The variable X_n is replaced with $X_n + \Delta X_n$ in step 108. In other words, a trial is executed.

In step 109, the difference ΔE between previous and subsequent cost functions E which give a change ΔX_n is calculated as follows:

$$\Delta E = E(x_1, ..., x_n + \Delta x_n, ..., x_{2N}) - E(x_1, ..., x_n, ..., x_{2N}) \quad (10)$$

If $\Delta E < 0$, the change ΔX_n is then accepted in step 111. That is, calculation program is returned to step 106 for trial of next variable X_{n+1} via steps 112 and 105 while $X_n + \Delta X_n$ is taken as X_n. If $\Delta E > 0$, whether the change ΔX_n is accepted or refused is determined according to a probability $P(\Delta E) = \exp(-\Delta E/T)$ depending upon temperature as shown in steps 113, 114 and 116. If it is determined that the change is accepted, the calculation program returns to step 106 via steps 115 and 105 while taking $X_n + \Delta X_n$ as new X_n. If the change is determined to be refused, X_n and the cost function E are returned to original values in step 117 and the program is returned to step 106 via steps 118 and 105.

Such a series of steps are executed for each variable, that is, for n = 1 through 2N. This operation is repeated total N_T^{max} times. It is adequate that, for example, a value of about 100 to 400 is adequate as N_T^{max}.

N_1 in step 112 of a flow chart of Fig. 2A denotes a number of changes accepted in such a direction that the cost function is decreased, N_2 in step 115 denotes the number of changes accepted in such a direction that the cost function is increased. N_3 in step 105 denotes the number of the refused changes. When it is found in step 105 that N_T^{max} trials are completed, the program proceeds to step at which determination whether or not the temperature T determining the probability of acceptance of change is lowered is performed. That is, it is determined based on a value of $|N_1 - N_2|$ whether or not the number N_1 of increases of the cost function of the accepted trials approximates to the number of decreases of the cost function. If this value is not less than ϵ (for example, about 0.02), the program is returned to step 103 without changing the temperature and trials will be repeated N_T^{max} times. If the value of $|N_1 - N_2|/N$ is lower than ϵ, the program proceeds to step 120. By lowering the temperature T, the probability that the change to make $\Delta E > 0$ is accepted is decreased and thereafter the program proceeds to step 103 and the trials are similarly repeated N_T^{max} times.

An approach to make $T_k = \xi T_{k-1}$, as k-th temperature step is adopted in the present embodiment to lower the temperature T in step 120. A value of about 0.9 through 0.95 is used as ξ at this time. Another approach to lower the temperature by $T_k = T_0/(1+k)$ or $T_k = T_0/\log(e+k)$ is also proposed in a literature A Vol. 122, p157, 1987 (H. Szu et al., "Fast Simulated Annealing", Physics Letters A, Vol. 122, p157, 1987.

As N_T^{max} trials of changes of each variable and repeated in some cycles while gradually lowering the temperature T as mentioned above, each variable approximates to an optimum value and the accepted change is gradually decreased. When it is determined that $N_1 + N_2 = 0$, in step 118, that is, there is no accepted change of the tried changes, a variable which minimizes the cost function, that is, optimum location and current vectors of a current dipole are obtained. Therefore, simulated annealing operation is ended.

Although the present embodiment has been described with reference to a case in which simulated annealing is used for optimization operation, the present invention is not limited to this case. The other algorithms which can find out a true minimum value from a function containing a localized minimum value, such as Genetic Algorithm proposed by J. H. Holland can be used.

If areas at which dipoles exist are a priory known in advance, the priory information can be incorporated into the optimization operation as follows:

In this case, each estimate which minimizes E which is calculated by the following equation (11) in lieu of equation (4) is determined.

$$E(\hat{r}_1, \hat{r}_2, \ldots, \hat{r}_N; \hat{q}_1, \hat{q}_2, \ldots, \hat{q}_N)$$

$$= \sum_{m=1}^{M} (D_m - \hat{D}_m)^2 + Es(\hat{q}_1, \ldots, \hat{q}_N)$$

$$+ E_L(\hat{r}_1, \ldots, \hat{r}_N) \qquad \ldots\ldots (11)$$

E_L is defined as follows:

1) If all $\hat{r}_1, \ldots, \hat{r}_N$ exist in preliminarily preset areas, $E_L(\hat{r}_1, \ldots, \hat{r}_N) = 0$

2) If any of $\hat{r}_1, \ldots, \hat{r}_N$ moves out of the preliminarily preset areas, $E_L(\hat{r}_1, \ldots, \hat{r}_N) = \Lambda$ wherein is a value which is sufficiently high for the current temperature T_1 that is, such a value that

$$\exp(-\Lambda/T) \doteq 0.$$

exp By defining E_L in such a manner, the probability that a change by which each $\hat{r}_n$ moves out of the preliminarily preset area is accepted is approximately zero. An estimate which minimizes

$$E(\hat{r}_1, \ldots, \hat{r}_N; \hat{q}_1, \ldots, \hat{q}_N)$$

$$= \sum_{m=1}^{M} (D_m - \hat{D}_m)^2 + Es(\hat{q}_1, \ldots, \hat{q}_N)$$

can be determined in preliminarily preset area.

Although a case has been described in which the second amount expressed by equation (5) or (5'), that is, the magnetic field created by the assumed current dipole is used as the second term of equation (4) for restricting the freedom degree, equation (5") of the total sum of absolute values of current vectors of the presumed current dipoles or equation (5''') of the α-th power of the total sum may be used in lieu of equation (5) or (5').

$$Es(\hat{q}_1, \hat{q}_2, \ldots, \hat{q}_N) = w \sum_{n=1}^{N} |q_n| \qquad (5'')$$

$$Es(\hat{q}_1, \hat{q}_2, \ldots, \hat{q}_N) = w \sum_{n=1}^{N} |q_n|^{\alpha} \qquad (5''')$$

In equation (5") and (5'''), the meaning of w and α are same as those of equations (5) and (5').

Since terms of position vectors are included in equations (5) and (5"), the freedom degree is more restricted than in equations (5") and (5''').

Claims

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1. A process for measuring the distribution of the biocurrent by measuring the biomagnetic field generated by the activity of a living body at a plurality of measuring points (12-1, ..., 12-M) to indirectly determine the distribution of the isolated currents (q_n) in said living body from the plural measured values of the magnetic field, comprising the steps of:
measuring the actual magnetic field at said measuring points (12-1, ..., 12-M);
assuming multiple currents move than the number of said isolated currents possibly existing in said living body to preset the locations and the current vectors of the assumed currents;
calculating a virtual magnetic field at each measuring point from the estimated location and current vectors; and
determining including consecutively changing the estimated location and current vectors of said assumed currents to decrease the difference between said virtual and actual magnetic fields so that the estimated location and current vectors of the assumed currents having the number corresponding to the true isolated currents substantially approximate to the true values and the estimates of the others assumed currents approximate to zero.

2. A process for measuring the biocurrent distribution as defined in Claim 1 in which said determining step includes the steps of:
a changing said estimated location and current vectors;
calculating a first amount representative of the difference between said virtual and actual magnetic fields;
calculating a second amount from each of said estimated current vectors; and
determining said estimated location and current vectors from said first and second amounts.

3. A process for measuring the biocurrent distribution as defined in Claim 2 in which said step of determining said estimated location and current vectors includes presetting a cost function including at least said first and second amounts and determining the estimated location and current vectors by using the cost function.

4. A process for measuring biocurrent distribution as defined in Claim 3 in which said cost function includes a linear sum of said first and second amounts.

5. A process for measuring the biocurrent distribution as defined in Claim 4 in which said step of determining said estimated location and current vectors is executed by minimizing the cost function.

6. A process for measuring the biocurrent distribution as defined in Claim 4 in which said second amount is the total sum of the absolute values of said estimated current vectors.

7. A process for measuring the biocurrent distribution as defined in Claim 4 in which said second amount is the total sum of the α-th power (α is a positive real number) of the absolute values of said estimated current vectors.

8. A process for measuring the biocurrent distribution as defined in Claim 4 in which said second amount is the total sum of the absolute values of the magnetic fields, each created at each measuring point by each of said assumed current vectors.

9. A process for measuring the biocurrent distribution as defined in Claim 4 in which said second amount is the total sum of the absolute values of the magnetic field's components normal to the surface of said living body, each magnetic field being created by each of said assumed current vector at each measuring point.

10. A process for measuring the biocurrent distribution as defined in Claim 4 in which said second amount is the total sum of α-th power (α is a positive real number) of absolute values of the magnetic field's components normal to the surface of said living body, each magnetic field being created by each of said assumed current vector at each measuring point.

11. A process for measuring the biocurrent distribution as defined in Claim 7 or 12, in which $\alpha \neq 1$, preferably $0 < \alpha < 1$.

12. A process for measuring the biocurrent distribution as defined in Claim 5 in which said step of determining said estimated location and the current vectors includes a first step of accepting a change in said estimates executed in the step of changing said estimates when said cost function decreases, and a second step of accepting a change in said estimates in a probability relating to a given temperature even when said cost function increases.

13. An apparatus of measuring the biocurrent distribution by measuring the magnetic field generated by the activity of a living body at a plurality of measuring points (12-1, ..., 12-M) to indirectly determine the distribution of isolated currents (q_n) in the living body from the plural measured values of the magnetic field, comprising:

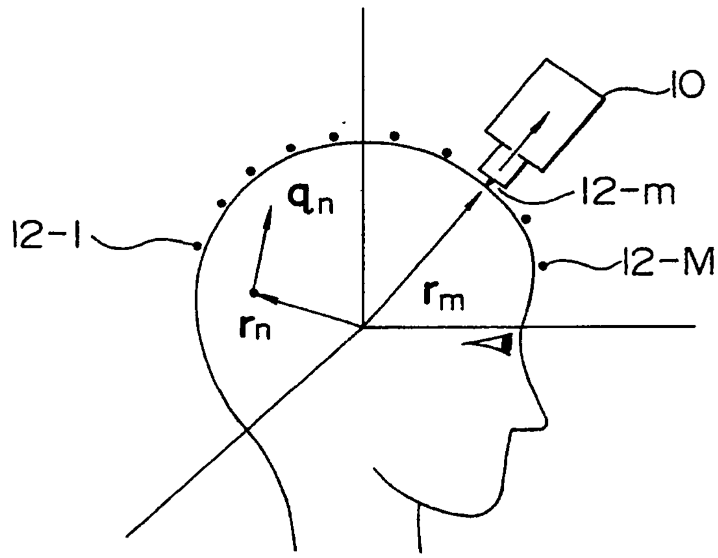
means for measuring the actual magnetic field at said measuring points (12-1 ..., 12-M);

means for assuming multiple currents more than the number of said isolated currents possibly existing in said living body to preset the location and the current vectors of the assumed current;

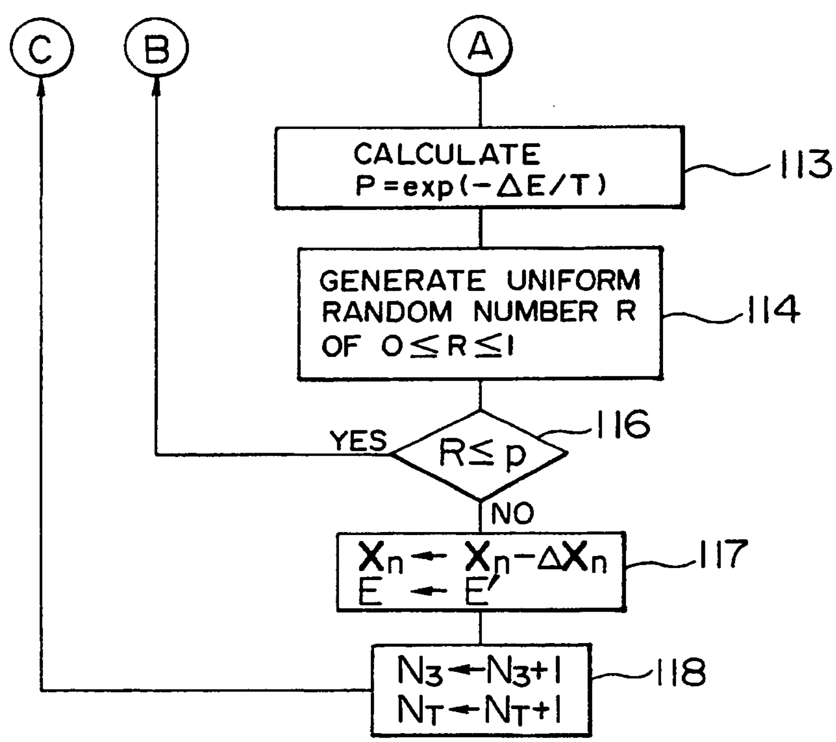
means for calculating a virtual magnetic field at each measuring point from the estimated location and current vectors; and

determining means including consecutively changing the estimated location and current vectors of said assumed currents to decrease the difference between said virtual and actual magnetic fields so that the estimated location and current vectors of the assumed currents having the number corresponding to the true isolated currents substantially approximate to the true values and the estimates of the other assumed currents approximate to zero.

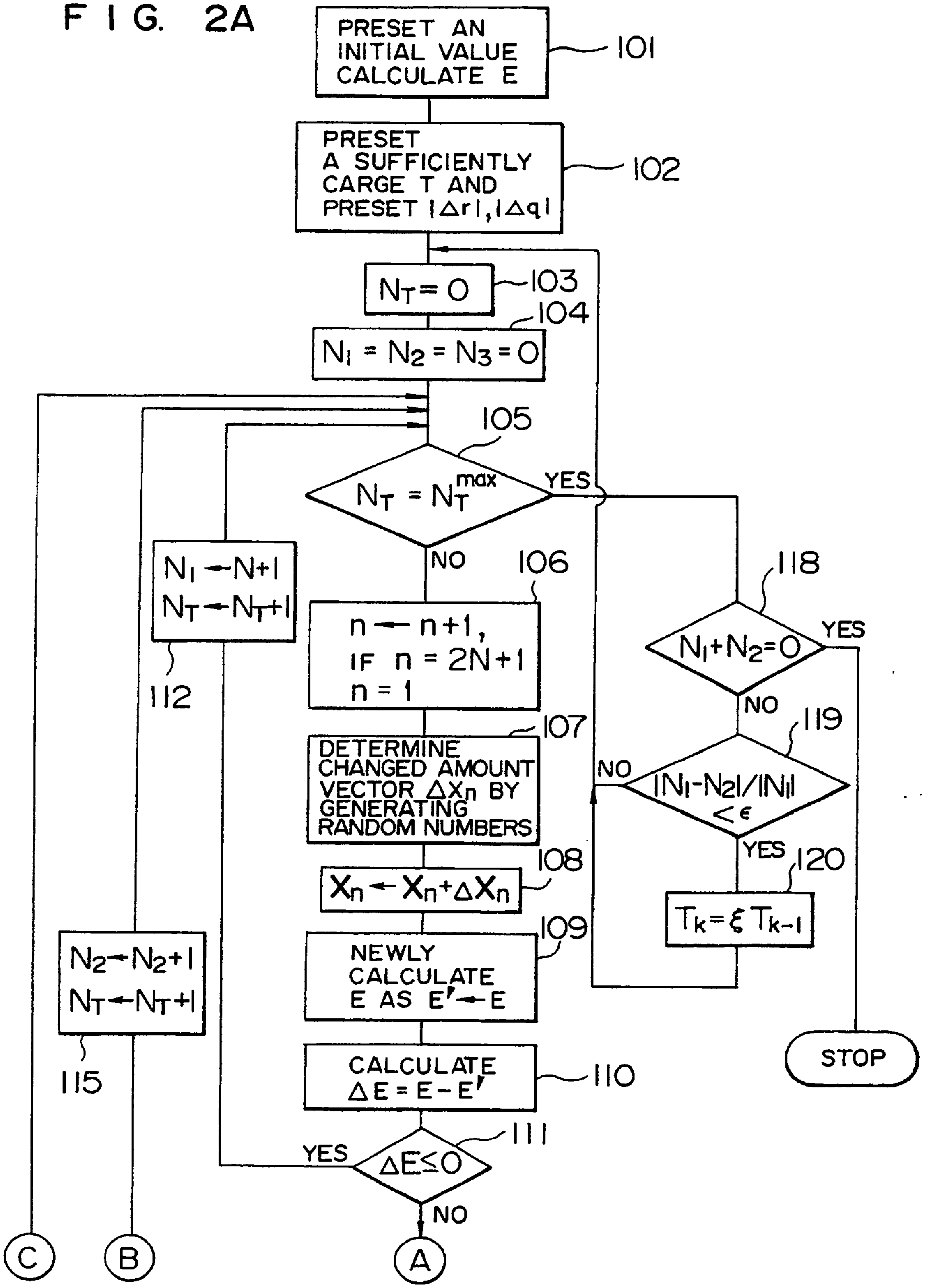
F I G. 1


10
12-m
12-1
q_n
12-M
r_m
r_n

F I G. 2B


C
B
A
CALCULATE
P=exp(−ΔE/T)
113
GENERATE UNIFORM
RANDOM NUMBER R
OF 0≤R≤1
114
YES
R≤p
116
NO
$X_n \leftarrow X_n - \Delta X_n$
$E \leftarrow E'$
117
$N_3 \leftarrow N_3+1$
$N_T \leftarrow N_T+1$
118

F I G. 2A


PRESET AN INITIAL VALUE CALCULATE E
101
PRESET A SUFFICIENTLY CARGE T AND PRESET |Δr|,|Δq|
102
NT = 0
103
N1 = N2 = N3 = 0
104
105
NT = NT max
YES
NO
106
n ← n+1, IF n = 2N+1 n = 1
107
DETERMINE CHANGED AMOUNT VECTOR ΔXn BY GENERATING RANDOM NUMBERS
108
Xn ← Xn+ΔXn
109
NEWLY CALCULATE E AS E' ← E
CALCULATE ΔE = E − E'
110
111
ΔE≤0
YES
NO
A
N1 ← N+1
NT ← NT+1
112
N2 ← N2+1
NT ← NT+1
115
B
C
118
N1+N2=0
YES
NO
119
|N1-N2|/|N1| < ε
NO
YES
120
Tk = ξ Tk-1
STOP

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 10 4808

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	ELECTRO MEDICA Band 57, Nr. 1, 1989, Seiten 2-7, Erlangen, DE; F. GUDDEN et al.: "Ein Vielkanalsystem zur biomagnetischen Diagnostik in Neurologie und Kardiologie: Prinzip, Methode und erste Ergebnisse" * Seite 2, Zusammenfassung; Seite 5, linke Spalte, Zeile 39 - Seite 6, linke Spalte, Zeile 2; Figuren 2,4,6 *	1	A 61 B 5/05 A 61 B 5/04
A	idem	2,13	
A	I.E.E.E. TRANSACTIONS ON BIOMEDICAL ENGINEERING Band BME-34, Nr. 12, Dezember 1987, Seiten 913-920, New York, NY, US; J.W.H. MEIJS et al.: "The EEG and MEG, using a model of eccentric spheres to describe the head" * Seite 913, linke Spalte, Zeile 15 - Seite 915, rechte Spalte, Zeile 6 *	1-10,13	
A	DE-A-3 725 532 (SIEMENS AG) * Zusammenfassung; Spalte 1, Zeile 61 - Spalte 2, Zeile 21; Spalte 3, Zeile 17 - Spalte 4, Zeile 28; Figuren 1,2 *	1-10,13	
A	US-A-4 486 835 (D. BAI et al.) * Spalte 3, Zeilen 1-37; Spalte 5, Zeilen 36-57 *	1,13	TECHNICAL FIELDS SEARCHED (Int. Cl.5) A 61 B 5/00 G 01 R 33/00

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
Berlin	04 July 91	WEIHS J.A.

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
Y: particularly relevant if combined with another document of the same catagory
A: technological background
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E: earlier patent document, but published on, or after the filing date
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&: member of the same patent family, corresponding document